CHANNELIZED COPLANAR WAVEGUIDE PIN-DIODE SWITCHES

G.E. Ponchak* and R.N. Simons**

ABSTRACT

Three different types of p-i-n diode, reflective CPW switches are presented. The first two switches are the series and the shunt mounted diode switches. Each has achieved greater than 15 dB of isolation over a broad bandwidth. The third switch is a narrow band, high isolation switched filter which has achieved 19 dB of isolation. Equivalent circuits and measured performance for each switch is presented.

INTRODUCTION

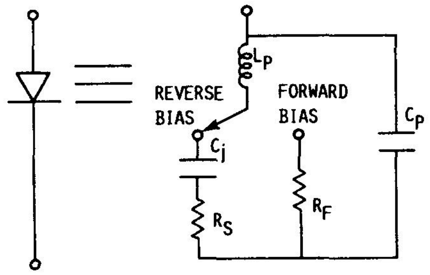
Coplanar waveguide, CPW, on a dielectric substrate consists of a center strip conductor with semi-infinite ground planes on either side (1). Channelized coplanar waveguide, CCPW, consists of CPW transmission line placed in a metal enclosure (2). Because the ground planes and the center conductor are on the same side of the substrate, shunt as well as series mounting of circuit components can be done without the need for wraparounds or via-holes. The improvements in circuit yield and the reduction in inductance for ground paths over microstrip based circuits should permit microwave integrated circuits, MIC's, to be fabricated at higher frequencies and less expensively. However, the extent of applications of CPW circuits is limited due to the unavailability of circuit elements and models which can be incorporated into CAD programs.

Microwave switches are a basic circuit element for phase shifters and radiometers. A CPW switchable attenuating medium propagation, SAMP, switch has been demonstrated by Fleming et al. (3). This device is useful for GaAs MMIC circuits but it is not easily incorporated into MIC's on passive substrates such as alumina or duroid. P-i-n diodes are good microwave switches since the impedance of the diode can be changed from a very high value to nearly zero in a short time (4,5).

This paper presents for the first time CPW p-i-n diode, reflective switches. Three basic switches are presented. The first is a shunt mounted diode switch. This switch is similar to fin line shunt mounted diode switches (4). The second switch is a series mounted diode across a gap in the center strip conductor. The last switch is a novel design which converts a CPW interdigital coupler with bandpass filter characteristics into a spurline, bandstop filter.

The three switches have been fabricated on CCPW transmission lines. All of the circuits have been fabricated on RT/Duroid 5880 substrates with Metelics Corporation beam lead diodes, MBP-1030-B11. Figure 1 is the equivalent circuit of the diode with the circuit element values supplied by Metelics. Although no tuning to resonate off the diode parasitics was

*NASA Lewis Research Center, 21000 Brookpark Road, Cleveland, Ohio 44135, U.S.A.
**NASA Resident Research Associate from Case Western Reserve University, Cleveland, Ohio 44106, U.S.A.



TYPICAL VALUES SUPPLIED BY METELICS	
R_S	0.2Ω
R_f	6.0Ω
L_p	0.1 nH
$C_T = C_j + C_p$	0.03 pF

FIGURE 1. - P-I-N DIODE EQUIVALENT CIRCUIT AND TYPICAL CIRCUIT ELEMENT VALUES.

done, the CPW slots were made equal to the length of the packaged diode to minimize the package inductance, Lp. Testing of the switches has been done on an HP 8510 automatic network analyzer with bias tees to supply the dc bias to the diodes. The test fixture is comprised of a 2 in. length of CCPW with a 0.045 in. center strip and 0.010 in. slot. Connection to 3.5 mm coax cables is made through a pair of coaxial connectors. Tuning notches in the ground plane have been used to improve the coax-to-CCPW characteristics over selected frequency bands. The test fixture has a total insertion loss of 0.5 dB and a return loss greater than 15 dB for the frequencies reported in this paper.

P-I-N DIODE SHUNT SWITCH

In a shunt mounted configuration, a pair of diodes are placed in parallel across the slots of the CCPW transmission line (Fig. 2). When the diodes are forward biased, each slot is loaded by the forward bias impedance of the diode; at 10 GHz, the impedance across the slot is approximated by $Rf + j\omega Lp \approx 8.7\ \Omega \ll Zo$. The shunt impedance for CPW, with two parallel slots, is therefore 4.35 Ω. This low impedance loading the slot reflects the propagating wave. When the diode is reverse biased, each slot is loaded by an impedance approximated by $1/(j\omega Ct) \approx 530\ \Omega \gg Zo$. This is an equivalent shunt impedance of 265 Ω for CPW. This load results in a small attenuation. Using expressions by Watson (6) modified for two parallel shunt elements, an isolation of 16 dB and an insertion loss of 0.04 dB predicted.

An insertion loss less than 1 dB and an isolation of 15 dB has been measured over the frequency band of 8 to 11 GHz. By incorporating more than

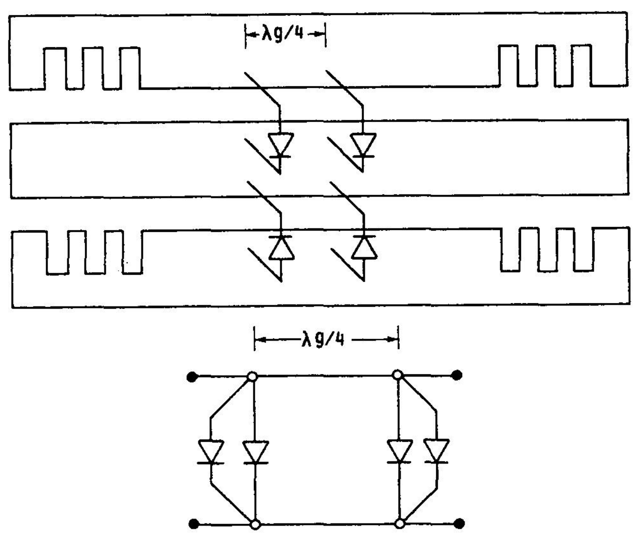


FIGURE 2. - SCHEMATIC AND EQUIVALENT CIRCUIT OF CPW P-I-N DIODE SHUNT SWITCH.

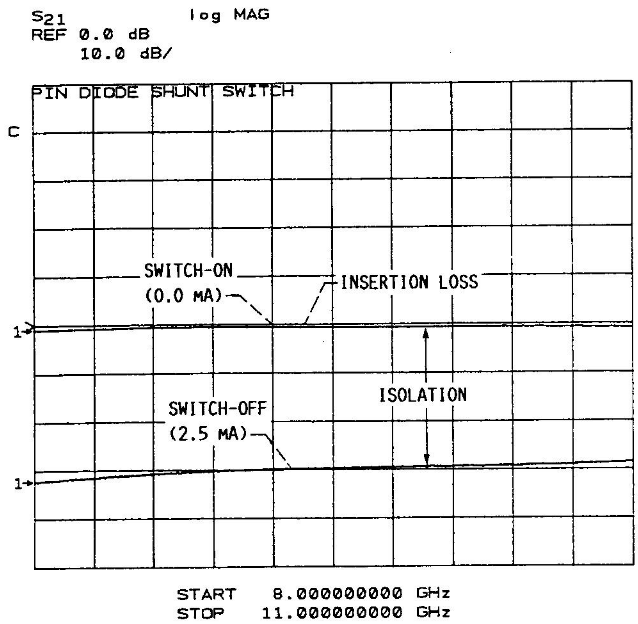


FIGURE 3. - MEASURED INSERTION LOSS AND ISOLATION OF CPW P-I-N DIODE SHUNT SWITCH WITH TWO PAIRS OF DIODES.

one pair of diodes across the slots with a $\lambda g/4$ separation, higher isolation can be achieved. Typically, two pairs of diodes have resulted in an isolation of 30 dB over the 8 to 11 GHz frequency band with little increase in insertion loss, this is shown in Fig. 3.

P-I-N DIODE SERIES SWITCH

In the series mounted diode configuration, a diode is mounted across an 0.008 in. gap in the center strip conductor of the CCPW line (Fig. 4). The center strip has been tapered to the width of the beam lead diode to provide a better match to the width of the diode package. The gap appears as an equivalent capacitive π network (7). When the diode is forward biased, the coupling capacitance is shorted by the low diode impedance and the wave is transmitted. Reverse biasing the diode results in an impedance across the gap which can be approximated by $1/[j\omega(Ct + Cc)] >> Zo$ at 10 GHz. Therefore, the propagating signal is reflected as if from an open circuit. A measured insertion loss of 1 dB and an isolation of 15 dB has

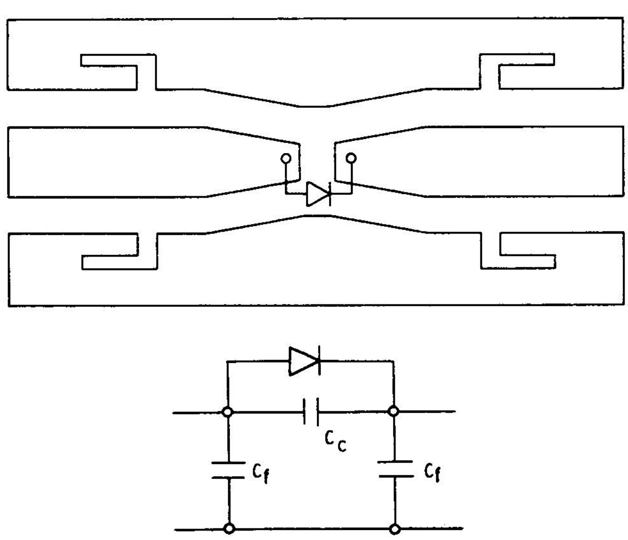


FIGURE 4. - SCHEMATIC AND EQUIVLENT CIRCUIT OF CPW P-I-N DIODE SERIES SWITCH.

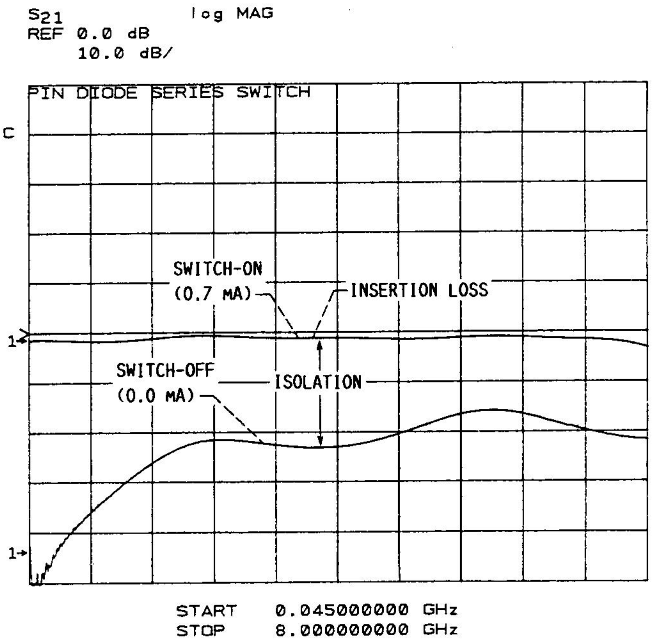


FIGURE 5. - MEASURED INSERTION LOSS AND ISOLATION OF CPW P-I-N DIODE SERIES SWITCH.

been obtained from 0.045 to 8 GHz (Fig. 5). The gap impedance is not large enough at higher frequencies to provide good isolation. The gap can be lengthened to decrease Cc but the increase in inductance from the longer diode leads will ultimately limit the gap separation. Resonating out these reactances is required for higher frequency operation (6).

P-I-N DIODE SPDT SWITCH

To realize a SPDT switch, a CCPW Tee-junction with gaps in the center strip conductor at the junction was formed (Fig. 6). Diodes were mounted across the gaps in parallel. As shown in Fig. 7, the measured insertion loss is 1 dB and the isolation is greater than 15 dB over the octave bandwidth of 2.25 to 5.5 GHz.

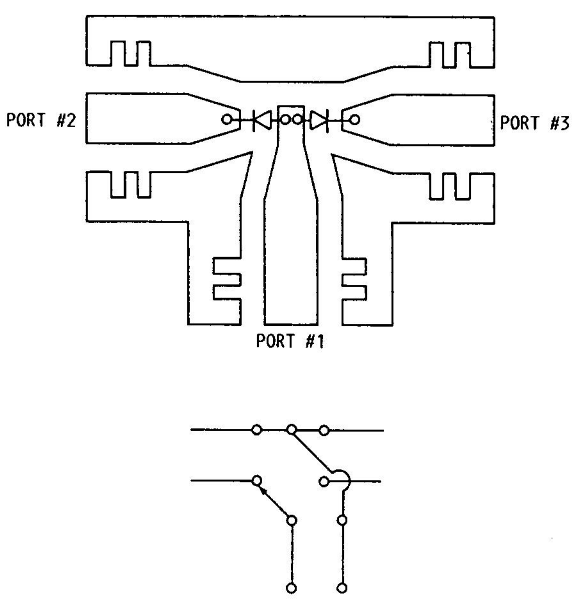


FIGURE 6. - SCHEMATIC AND EQUIVALENT CIRCUIT OF SERIES MOUNTED P-I-N DIODE CPW SPDT SWITCH.

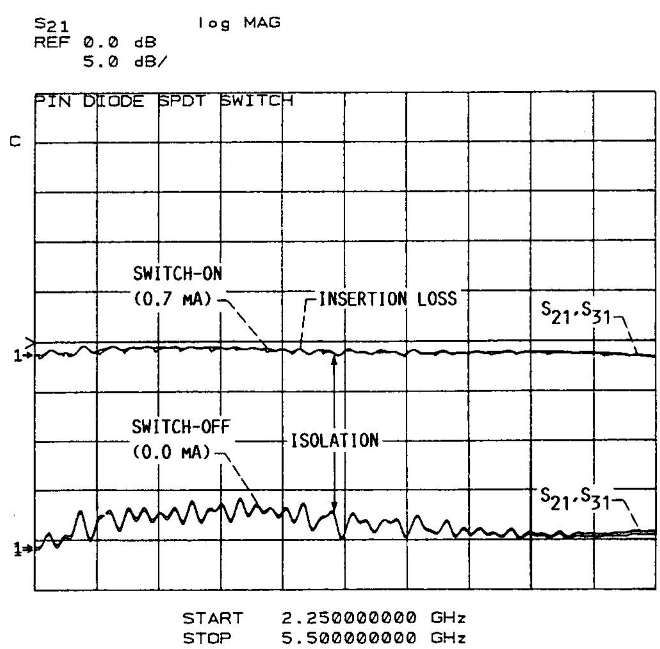


FIGURE 7. - MEASURED INSERTION LOSS AND ISOLATION OF SERIES MOUNTED PIN DIODE CPW SPDT SWITCH.

P-I-N DIODE SWITCHED-SERIES-STUB SWITCH

A diode is mounted across the open end of a λg/4 stub which is in series with the center strip conductor of the CCPW as shown in Fig. 8. When the diode is unbiased, the stub is terminated in an effective open circuit and therefore appears as a series short circuit. Hence, the wave propagates with negligible attenuation. This is the on-state of the switch. When the diode is forward biased, the stub is terminated in an effective short circuit which therefore appears as a series open circuit. The wave is therefore reflected; this is the off-state of the switch. The diode reactances result in an effective lengthening of the stub and can easily be compensated for. A measured insertion loss of 1.0 dB and an isolation of 19 dB has been obtained at 9 GHz (Fig. 9).

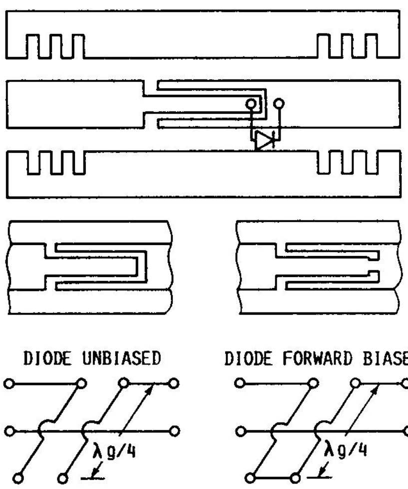


FIGURE 8. - SCHEMATIC AND EQUIVALENT CIRCUIT OF CPW P-I-N DIODE SWITCHED-SERIES-STUB SWITCH.

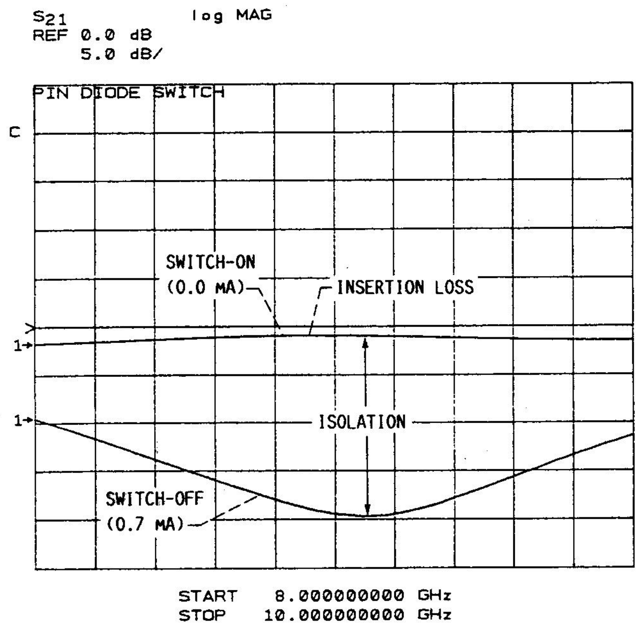


FIGURE 9. - MEASURED INSERTION LOSS AND ISOLATION OF CPW P-I-N DIODE SWITCHED-SERIES-STUB SWITCH.

CONCLUSIONS

P-I-N diode reflective switches are easily realizable on CCPW transmission line and therefore CPW transmission line. Each of the three type of switches presented are practical for specific applications. The performance of the switches could be improved through typical tuning of the diode reactances once the necessary CPW circuit models become available.

REFERENCES

1. Wen, C.P., "Coplanar Waveguide, A Surface Strip Transmission Line Suitable for Nonreciprocal Gyromagnetic Device Applications," 1969, IEEE Trans. Microwave Theory Tech., vol. MTT-17, pp. 1087-1090.

2. Simons, R.N., Ponchak, G.E., Martzaklis, K.S., and Romanofsky, R.R., "Channelized Coplanar Waveguide: Discontinuities, Junctions, and Propagation Characteristics,: 1989, IEEE MTT-S International Microwave Symposium Digest, IEEE, Piscataway, NJ, pp. 915-918.

3. Fleming, P.L., Smith, T., Carlson, H.E., and Cox, W.A., "GaAs SAMP Device for Ku-Band Switching," 1979, IEEE Trans. Microwave Theory Tech., vol. MTT-27, pp. 1032-1035.

4. Bhat, B., and Koul, S.K., Analysis, Design and Applications of Fin Lines, Artech House, Norwood, MA, 1987.

5. White, J.F., Microwave Semiconductor Engineering, Van Nostrand Reinhold Co., New York, 1982.

6. Watson, H.A., Microwave Semiconductor Devices and Their Circuit Applications, McGraw-Hill Book Company, New York, 1969.

7. Simons, R.N., and Ponchak, G.E., "Modeling of Some Coplanar Waveguide Discontinuities," IEEE Trans. 1988, Microwave Theory Tech., vol. MTT-36, pp. 1796-1803.